Contamination of drinking water between source and point-of-use in rural households of South Africa and Zimbabwe: implications for monitoring the Millennium Development Goal for water

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Abstract:

Aims: To assess contamination of drinking water in rural Zimbabwe and South Africa

Methods: We conducted a cohort study of 254 children aged 12-24 months in rural South Africa and Zimbabwe. In dry and wet seasons, we measured water quality, using the indicator organism *E. coli,* at improved and unimproved sources, in household storage and drinking cups. We also recorded hygiene and socio-economic factors for each household.

Results: For improved sources, samples with *E. coli* counts less than 10 cfu/100ml were as follows: at source: 165 (88%); in household storage 137 (59%); in drinking cups 91 (49%). The corresponding values for unimproved sources were: source 47 (29%); household storage 32 (19%); drinking cups 21 (18%). This significant deterioration in microbial quality of water from improved sources was seen in both countries and both survey rounds.

Conclusion: Although improved sources generally delivered 'safe' water at the point-of-supply, 12% of source samples were contaminated and as such were 'unsafe'. Furthermore, in household storage, more than 40% of samples were 'unsafe'. For monitoring the Millennium Development Goal for water, UNICEF-WHO are assuming an equivalence between 'improved' sources and 'safe' water. Our findings suggest that this equivalence may be unsound.

Keywords: Developing Countries, Household Water Storage and Treatment (HWST), Hygiene, Intervention, Monitoring, Regulations.

Introduction

Diarrhoeal diseases account for 4.3% of the total global disease burden (62.5 million DALYs). An estimated 88% of this burden is attributable to unsafe drinking water supply, inadequate sanitation, and poor hygiene. These risk factors are second, after malnutrition, in contributing to the global burden of disease. (Pruss et al, 2002).

Target #10 of the Millennium Development Goal for water (number 7) is to *"Reduce by half the proportion of people without sustainable access to safe drinking water."* Because many developing countries have little or no water quality monitoring, particularly in rural areas, the organisations responsible for assessing progress towards this target (UNICEF and WHO) have adopted the following indicator as a modified version of the target (United Nations, 2005): *"Indicator 30. Proportion of population with sustainable access to an improved water source, urban and rural."* This modified version implies an equivalence between 'safe' water and water from an 'improved' source. The justification for this equivalence is not provided on the referenced webpage.

In rural areas of most developing countries, women and children collect water from a communal source, often located several hundred metres from the home. The sources themselves may be unimproved (hand dug wells, unprotected springs, rivers), with low and seasonal flow rates, or improved (public taps, boreholes or pumps, protected wells, protected springs or harvested rainwater). A systematic review of 57 studies published before 2002 by Wright *et al.* (2004) showed that water contamination occurs between source and point-of-use. This pattern has been confirmed by subsequent studies of water contamination in rural Sierra Leone (Clasen and Bastable, 2003) and rural Honduras (Trevett, Carter and Tyrrell, 2005). However, it is unclear exactly when this contamination takes place.

The purpose of our study was to determine when this contamination might be taking place. To do this, we measured the quality of water at all points along the supply chain, from 'intrinsic' source (cf. 'accessible' source) to the drinking cup used by the child in the household (see Figure 1).

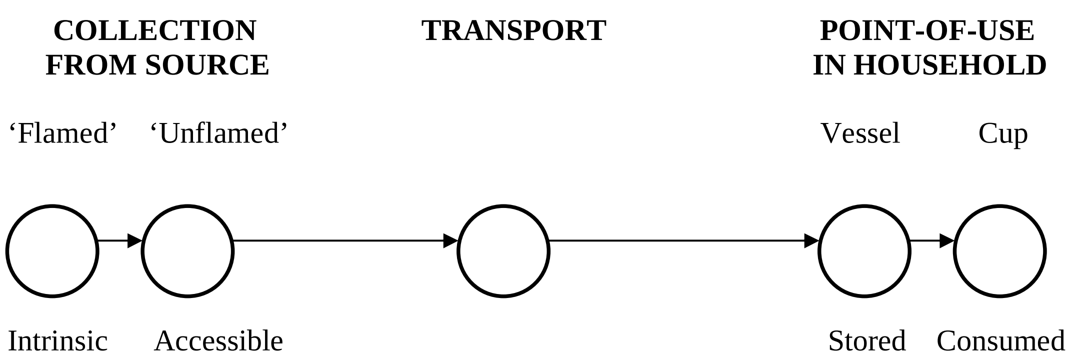

Figure 1: Showing the supply chain of drinking water for each household.

Methods

Study areas and sampling

The study areas were located in Venda District in Limpopo Province in South Africa and Zaka District in Masvingo Province in Zimbabwe. Census data indicated that both districts were below their respective national averages in terms of access to improved water supplies and sanitation improvements. Health centres in the study areas were ranked by rates of diarrhoea in children aged less than 5 years. Two villages from the worst five health centres in each area were selected for study. Within each village, 12 households with a child aged between 12 and 24 months were selected at random. The nature and purpose of the study was outlined in group meetings and explained in detail on an individual basis. The participants were then asked if they wished to be included. Where consent was withheld in whole or substantial part of the study, the household was replaced by one of additional sample households. Ethical approval for the project was obtained from the Research Ethics Committee of the Royal College of Surgeons in Ireland (reference REC 046).

Water sample collection

At each household, samples of water were obtained from the transport and storage vessels and the cup used by the child. Samples were also taken of the source water used by the household. In the case of sources which had a spout or tap (e.g. boreholes, capped wells and standpipes) two samples were taken: an 'unflamed' sample, representing the normal water quality that would be accessible by the household and a 'flamed' sample, representing the intrinsic water quality in the source. The 'flaming' procedure used a handheld gas burner to sterilise the spout, in accordance with WHO guidance (WHO, 1997). For wells where a bucket and windlass were in use, samples were taken from the bucket and directly from the well using a weighted sterile sample bottle on a line, also as per WHO guidance (WHO, 1997). Samples were sealed in 500 ml sterile plastic containers and stored on ice and water.

For all data collection, field survey teams were supplied with handheld computers, incorporating barcode readers. All samples were 'tagged' by barcode label in the field and linked in the computer records to the barcodes applied in the laboratory processes (Wright *et al.*, 2004). This created an effective 'audit trail' to ensure the completeness and accuracy of the processing of the samples. In addition to the water samples, descriptive data about water and sanitation practices were recorded in the households visited e.g. type of water source, type of water storage vessels, distance to source, sanitation type. The quality of the water samples was assayed in field laboratories set up in each study district. Total coliform and *E. coli* indicator bacteria were enumerated using the Colilert system (Covert *et al.*, 1989). Samples were diluted to allow for the higher levels of contamination characteristic of the water supplies in the region. In Venda, the dilution factor was 5:1 and in Zaka 10:1.

Water and sanitation practices

Data were also collected about water source type, water vessel type and material, water treatment used and sanitation facility. These data were entered using the handheld computers as part of the initial visit to the household.

Statistical analysis

Data were analysed with Stata Release 8, using interval regression to test for significant differences between different points along the 'chain' between source and point-of-use. This is a technique for the analysis of data where some observations are not known exactly but lie somewhere within a defined interval. For samples that were above the detection thresholds of the Colilert system, the value cannot be estimated exactly, but must be greater than or equal to the threshold. Likewise, where none of the cells of the Quantitray were positive, the value must be less than the minimum detectable level of the assay. The method requires that the data should come from a normal distribution. *E. coli* counts were therefore re-expressed in log (10) units before analysis. Secondly, the relationship between the more highly contaminated stored water samples (with *E. coli* counts >100 cfu / 100ml) and household hygiene behaviours and other characteristics was assessed using logistic regression.

Results and Discussion

The descriptive data about the water and sanitation practices in each household are summarized for the two districts in Table 1 below.

Household characteristic	**Venda Number**	**Venda Percent**	**Zaka Number**	**Zaka Percent**
Water source:				
Improved:				
Standpipe	83	67%	5	4%
Borehole/protected well	10	8%	37	31%
Sub-total improved	***93***	***75%***	***42***	***35%***
Unimproved				
Unprotected well	3	2%	33	28%
Unprotected spring	8	7%	22	19%
River/canal	13	11%	21	18%
Sub-total unimproved	***24***	***20%***	***76***	***65%***
Not recorded	7	5%	0	0%
TOTAL	*123*	*100%*	*118*	*100%*
Water vessel type:				
Small hole	73	59%	69	59%
Large hole/Uncovered	46	37%	49	41%
Not recorded/not applicable	4	4%	0	0%
TOTAL	*123*	*100%*	*118*	*100%*
Water vessel material:				
Plastic	117	95%	99	84%
Metal	2	2%	16	14%
Other	0	0%	3	2%
Not recorded/not applicable	4	3%	0	0%
TOTAL	123	*100%*	*118*	*100%*
Water treatment:				
None	118	96%	111	94%
Boiling	1	1%	5	4%
Chlorination	0	0%	0	0%
Filtration	0	0%	0	0%
Other treatment	0	0%	0	0%
Not recorded/not applicable	4	3%	2	2%
TOTAL	*123*	*100%*	*118*	*100%*
Sanitation:				
Flush W.C.	0	0%	0	0%
Pit latrine	67	54%	27	23%
None	55	45%	91	77%
Not recorded	1	1%	0	0%
TOTAL	*123*	*100%*	*118*	*100%*

Table 1 showing water and sanitation practices in sample households during the dry season.

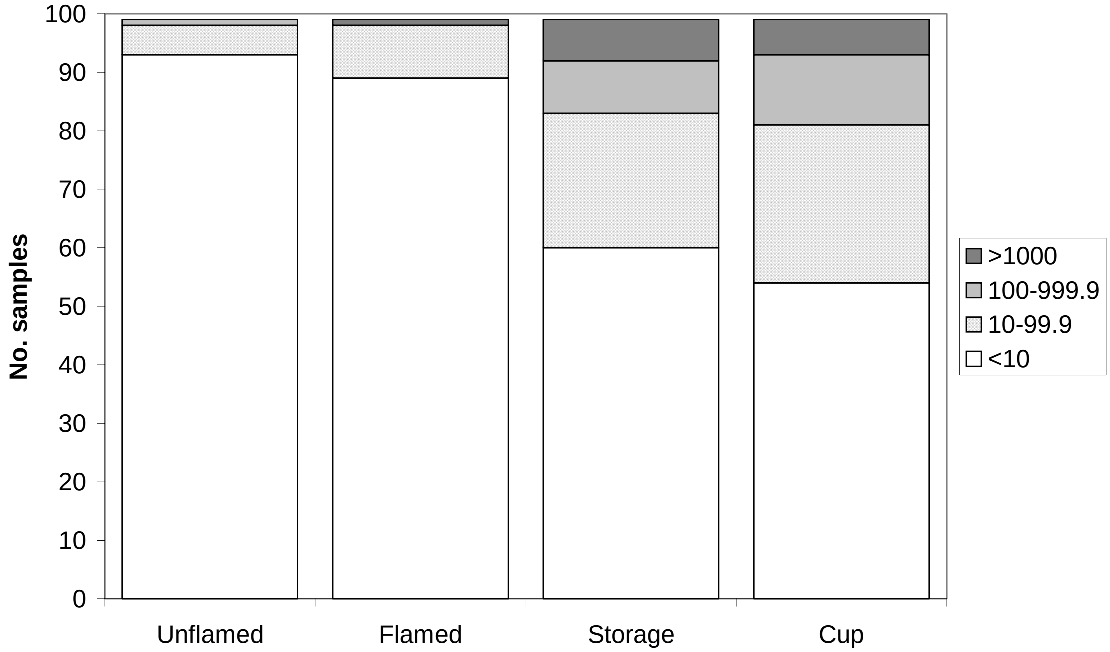

Figure 2: Showing percentage of contaminated samples for improved water sources in Venda, by source, household storage and cup (include 'unflamed' + 'flamed' sources again)

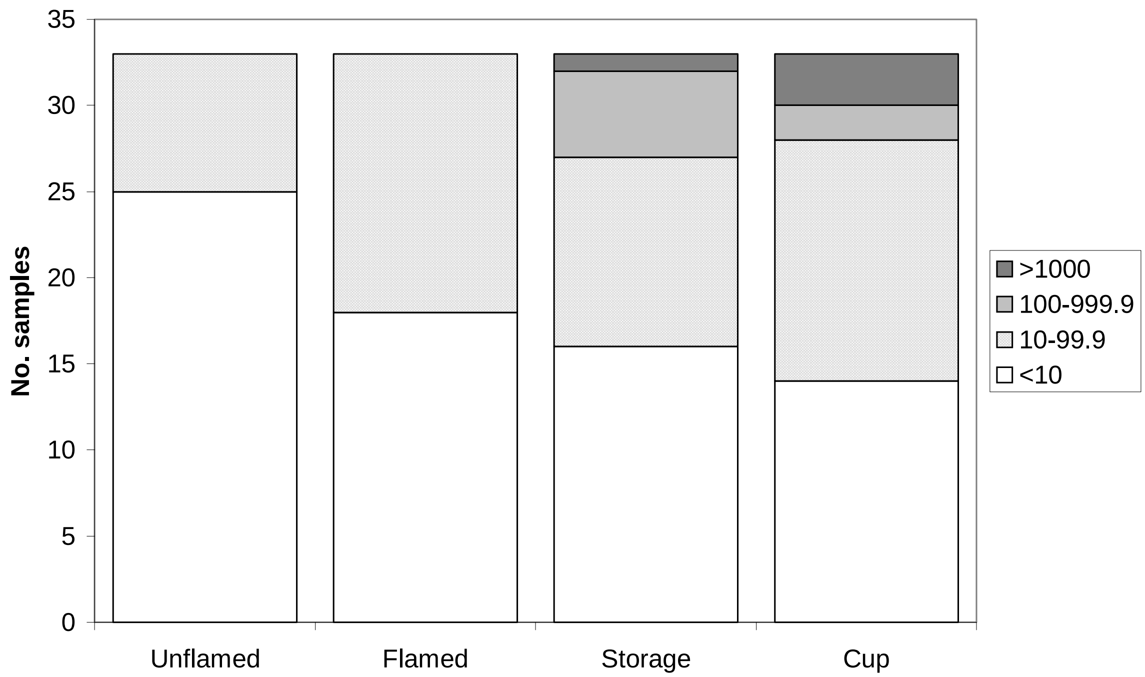

Figure 3: Showing percentage of contaminated samples for improved water sources in Zaka, by source, household storage and cup (include 'unflamed' + 'flamed' sources again)

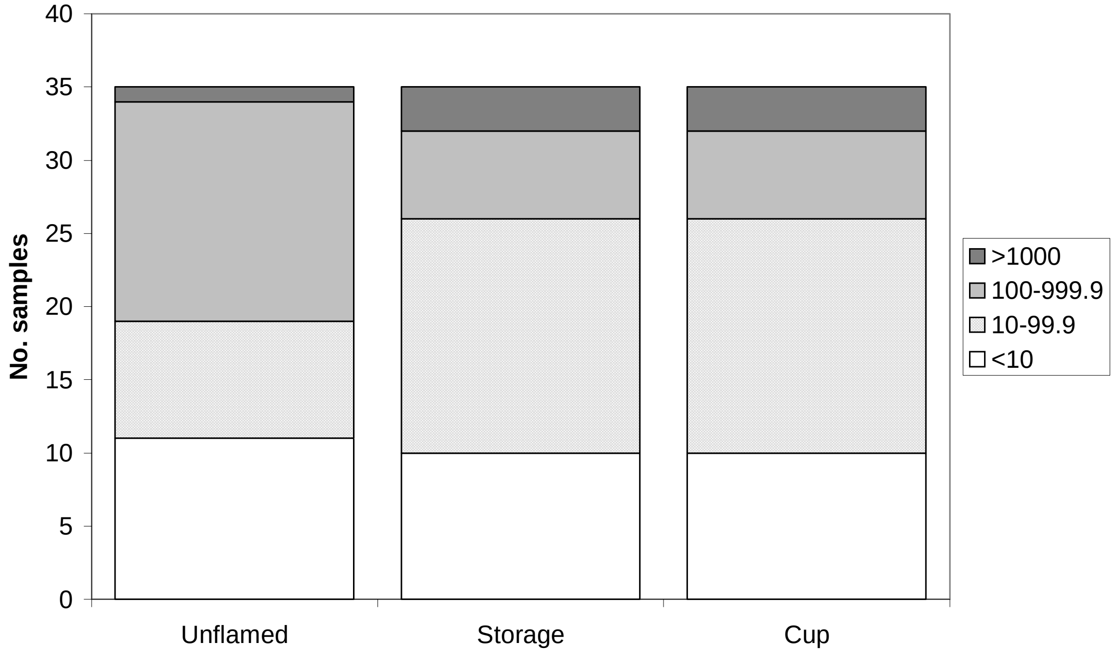

Figure 4: Showing percentage of contaminated samples for unimproved water sources in Venda, by source, household storage and cup.

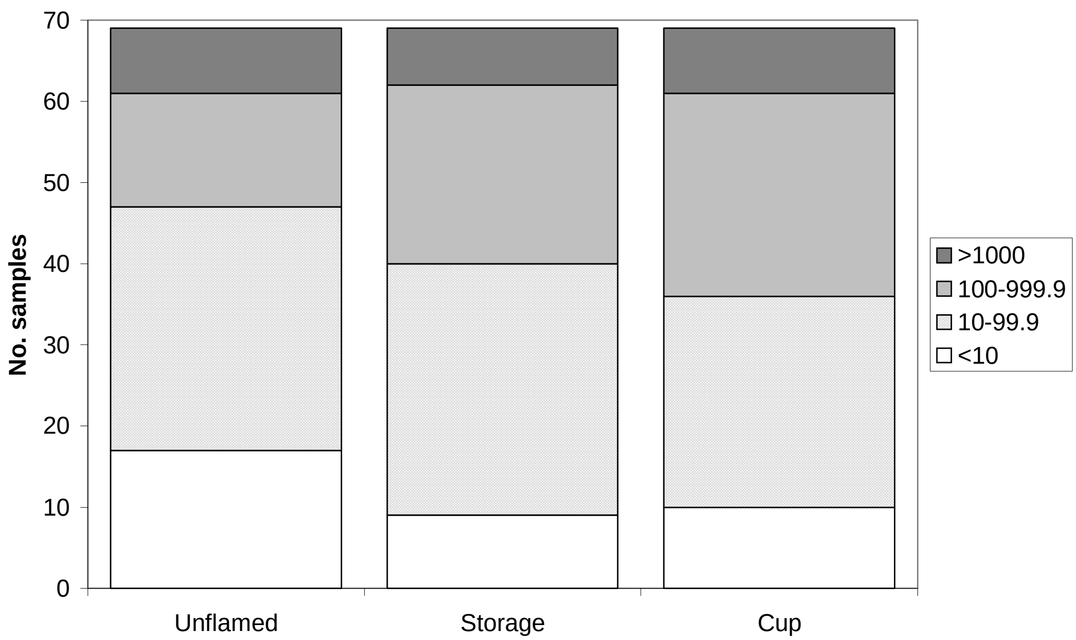

Figure 5: Showing percentage of contaminated samples for unimproved water sources in Zaka, by source, household storage and cup.

Changes in water quality along the 'chain' between source and point-of-use: Figures 2 – 5 show the change in quality at source, in household storage and drinking cup for improved and unimproved sources in the two study areas. Since most households had already collected their water by the time the survey team visited, the number of water samples collected from transport vessels was too low (n=16) to perform any analysis. Transport vessel data are therefore excluded from Figures 2-5 and any statistical analysis.

The interval regression analysis suggested that:

- There was no significant difference in water quality between the unflamed ('intrinsic') and flamed ('accessible') categories of source water samples.
- Samples collected from drinking cups were not significantly different from storage samples.
- There was however, a significant increase in contamination between source and storage for those collecting their water from improved sources.

Conclusion

Our findings confirm that although improved sources generally deliver 'safe' water at the point-of-supply, 12% of samples from such sources were contaminated with *E. coli* and as such were 'unsafe'. Our results also confirm the findings elsewhere (Wright et al, 2004; Trevett et al, 2005; Clasen and Barnstable, 2003) that the quality of water from improved sources deteriorates significantly after collection. More than 40% of the survey households using improved sources had water samples that were 'unsafe' at point-of-use (i.e. contained more than 10 cfu / 100 ml of *E. coli*). The Millennium Development Goal 7, Target #10, is being monitored using an equivalence between access to 'improved' sources and access to 'safe' water. Our findings suggest that this equivalence is unsound - providing an access to an improved source does not necessarily provide access to 'safe' drinking water.

However, we found that water from improved sources is of better quality at the point-of-use than water from unimproved sources and there is a strong correlation between the two sample points. This finding supports calls for point-of-use storage and treatment interventions such as home filtration and chlorination (Quick *et al.*, 2002). Because of the risk of post-collection water contamination, communities with improved supplies should also be targeted by such interventions.

The results presented here provide some indication as to when this post-collection contamination is occurring. As the 'intrinsic' and ' accessible' source water qualities were not found to differ significantly, this suggests that the contamination pathways at the improved supply points i.e. standpipes, boreholes and wellhead fittings are not providing a significant contribution to the overall post-collection contamination. Similarly, the deterioration between storage vessel and cup is not significant and this pathway is also less important. The significant deterioration that is occurring is attributable to mechanisms inside the transport and/or storage vessel. As noted in previous studies (Vanderslice and Briscoe, 1993), the increased *E. coli* counts in stored water may be due either to bacterial regrowth or to recontamination of water through dipping with hands and cups. The presence of biofilms on the inner surfaces may also offer a suitable medium for contaminating good quality water (Momba and Notshe, 2003).

The minimal amount of contamination from drinking cups identified here is consistent with the observed health benefits found in field trials of home water treatment and storage (Fewtrell *et al.*, 2005; Gundry *et al.*, 2004). If water from such treatment technologies were becoming contaminated through drinking cups, then their health benefits would be compromised and this was not the case. Flaming to purify taps and borehole fittings did not significantly decrease *E.*

coli counts in the water samples collected from improved sources. If this observation holds true for water samples collected in other developing country settings, this implies that flaming of water taps and boreholes may be unnecessary when collecting water samples for monitoring purposes.

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